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Convinced Exploration on Hybrid Aluminium Metal Matrix Composites

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***Abstract:** In the present investigation, the influence of Al2O3 & ash on the mechanical and Tribological behavior of Al 7075 composites is identified. Al 7075 particle reinforced composites were produced through casting, Mg added because the flux, to beat the wetting problem between reinforcement and liquid aluminium metal. The samples of Al 7075 composites were tested for hardness, tensile strengths and wear behavior. The test results showed increasing hardness of composites compared with the bottom alloy due to the presence of the increased ceramic phase. The wear and tear resistance of the composites increased with increasing content of reinforcement particles, and therefore the wear rate was significantly less for the material compared to the matrix alloy. A mechanically mixed layer containing oxygen and iron was observed on the surface, and this acted as an efficient insulation layer preventing metal to metal contact. The coefficient of friction decreased with increased reinforcement content and reached its minimum at 10 Wt% Al2O3 and ash.*

***Keywords:** Metal matrix, fly ash, particle reinforced, aluminium metal matrix, composites*

I. INTRODUCTION

Composite materials are formed by combining two or more materials that have quite different properties. Composites generally consist of fibers of high strength interfaced or bonded to a matrix with distinct interfaces between them. In this form both fibers and matrix retain their physical and chemical identities, yet they produce combination of properties that cannot be achieved with either constituents acting alone.

A. *Applications Of Metal Matrix Composites*

Embedding reinforcing members such as boron and silicon carbide fibers or stainless steel meshes into metal matrices is simple with Ultrasonic Additive Manufacturing. Since the process can be interrupted and modified at any point, structural components can be augmented into any metal matrix to form superior, high performance composite structures. These advanced materials can be stiff and lightweight, the perfect combination for high stress, weight-critical environments.

1) Strong, lightweight superstructures
2) Advanced welding process non detrimental to reinforcement material
3) CNC based part fabrication
4) Low cost matrix and reinforcement materials
5) Carbide drills are often made from a tough cobalt matrix with hard tungsten carbide particles inside.
6) Some tank armors may be made from metal matrix composites, probably steel reinforced with boron nitride. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
7) Some automotive disc brakes use MMCs. Early Lotus Elise models used aluminum MMC rotors, but they have less than optimal heat properties and Lotus has since switched back to cast-iron. Modern high-performance sport cars, such as those built by Porsche, use rotors made of carbon fiber within a silicon carbide matrix because of its high specific heat and thermal conductivity. 3M sells a preformed aluminum matrix insert for strengthening cast aluminum disc brake calipers , allowing them to weigh as much as 50% less while increasing stiffness. 3M has also used alumina performs for AMC pushrods.
8) Ford offers a Metal Matrix Composite (MMC) driveshaft upgrade. The MMC driveshaft is made of an aluminum matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far beyond the safe operating speeds of a standard aluminum driveshaft.
9) Honda has used aluminum metal matrix composite cylinder liners in some of their engines, including the B21A1, H22A and H23A, F20C and F22C, and the C32B used in the NSX.

10) Toyota has since used metal matrix composites in the Yamaha-designed 2ZZ-GE engine which is used in the later Lotus Lotus Elise S2 versions as well as Toyota car models, including the eponymous Toyota Matrix. Porsche also uses MMCs to reinforce the engine's cylinder sleeves in the Boxster and 911.
11) The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear.
12) Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frames for several years. Griffen Bicycles also makes boron carbide-aluminum MMC bike frames, and Univega briefly did so as well.
13) Some equipment in particle accelerators such as Radio Frequency Quadruples (RFQs) or electron targets use copper MMC compounds such as Glidcop to retain the material properties of copper at high temperatures and radiation levels.
14) Copper-silver alloy matrix containing 55 vol. % diamond particles, known as Dymalloy, is used as a substrate for high-power and high density multi-chip modules in electronics for its very high thermal conductivity.

MMCs are nearly always more expensive than the more conventional materials they are replacing. As a result, they are found where improved properties and performance can justify the added cost. Today these applications are found most often in aircraft components, space systems and high-end or boutique sports equipment. The scope of applications will certainly increase as manufacturing costs are reduced.

Composites have actually been in use for thousands of years. Adobe bricks were made using a composite of mud and straw. It is the combination of the physical properties of each material that gives the composite material many of its physical characteristics. Today's advanced composites, like carbon fiber, bring together combined properties we've come to know – lightweight, strong, durable and heat-resistant. Today, the benefits of components and products designed and produced in composite materials – instead of metals, such as aluminum and steel – are well recognized by many industries. Some of the advantages include:

a) High Strength to weight ratio
b) Corrosion Resistance
c) Wear Resistance
d) Stiffness
e) Fatigue Life
f) Temperature Dependent Behavior
g) Thermal Insulation
h) Thermal Conductivity
i) Acoustical Insulation
j) Low Electrical Conductivity
k) Visual Attractiveness
l) Radio translucent

B. Problem Definition

Zinc and bronze alloy have been used for many years for the production of small components and to certain extent for plain bearing. However the major disadvantages are low mechanical and creep strength at elevated temperatures and also long-term dimensional instability.

We can achieve the required properties of bearing material by using hybrid aluminium metal matrix composite. By using this material strength can increases and weight can reduce.

C. Objectives Of The Research Work

To improve the properties like
1) High Strength to weight ratio
2) Wear resistance
3) Hardness

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II. METHODOLOGY

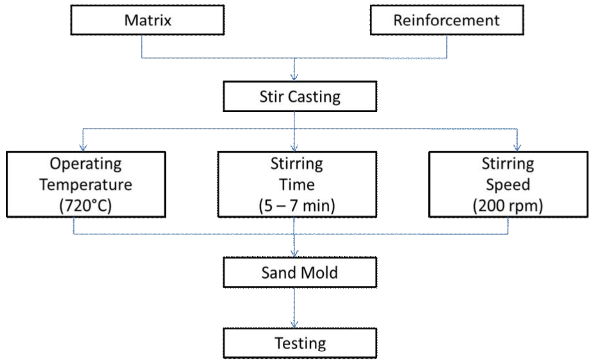

Figure: Methodology

III. SELECTION OF MATRIX

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

A. Aluminium as Matrix

The unique properties of aluminium composites are better compeer to other convention materials. So it prospects in aerospace and avionics. Compeer to magnesium the aluminium composites can use because design strong bonding, good corrosion resistance, good wettability, low density and flexibility's high. Titanium has been used in aerospace engines mainly for its higher elevated temperature resistance properly. Magnesium is the potential material to fabricate composite for making pistons, gudgeon pins, reciprocating components in motors and spring caps. It is also used in aerospace due to its properties like low coefficient of thermal expansion and high stiffness properties combined with low density. In metal matrix composites magnesium and magnesium alloys are among the lightest candidate materials for practical use as the matrix phase. And it has low density and excellent mach inability. However, it has been reported by several authors that though their low density (35% lower than that of Al) makes them competitive in terms of strength/density values. Magnesium alloys do not compare favorably with aluminium alloys in terms of absolute strength (Hunt Jr 2004).

Nowadays the need for high performance, high corrosion resistance, good friction, wear resistance, structural materials, and lightweight mostly used in Aerospace, Automotive and Consumer related industries, provided the necessary impetus for the development and emergence of Metal Matrix Composites (Basavarajappa, Chandramohan et al. 2004).

Aluminium-based alloys are developed to use in high performance engine bearings. Recent advances in engine technology have seen the introduction of new materials. Al-based bearing materials have been used in the crank shaft bearings. To improvement the efficiency of the internal combustion engine, aluminium MMCs can be used as journal bearings today. The composites has such properties like high thermal conductivity, low cost, co-activation with steel shafts, resistance to corrosive effects, fatigue strength, lightness and workability. Al-based MMCs bearing materials have higher fatigue strength than white metal bearings and also it can use at higher working temperatures (Feyzullahoğlu and Şakiroğlu 2010).

In general, the major advantages of aluminium matrix composites over iron, steel and other non-ferrous metals are as follows:

1) High specific strength
2) High specific stiffness
3) Higher elevated temperature strength
4) Improved wear resistance
5) Low density; high strength to weight ratio
6) Improved damping capabilities
7) Tailor able thermal expansion coefficients
8) Good corrosion resistance

So now a day's composite place a wider role in engineering application compare with conventional materials.

B. Aluminium Alloy 7075

Aluminium alloy 7075 is an aluminium alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable.

C. Chemical Composition for Aluminum Alloy 7075

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total	Al. Min
7075	0.40	0.50	1.2-2.0	0.30	2.1-2.9	0.18-0.28	5.1-6.1	0.20	0.05	0.15	Rem

Table: Chemical Composition for Aluminum Alloys 7075

7075 aluminum alloy's composition roughly includes 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals.

IV. SELECTION OF REINFORCEMENT

Reinforcements for metal matrix composites have a manifold demand profile, which is determined by production and processing and by the matrix system of the composite material. The following demands are generally applicable:

1) Low density
2) Mechanical compatibility
3) Chemical compatibility
4) Thermal stability
5) High Young's modulus
6) High compression and tensile strength
7) Good process ability
8) Economic efficiency

A. Aluminium Oxide [Al_2O_3]

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. It is commonly called alumina, and may also be called a oxide, aloxite, or alundum depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase α-Al_2O_3, in which it comprises the mineral corundum, varieties of which form the precious gems ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point. Al_2O_3 particulates can be used as reinforcement, whiskers or fibers to improve the properties of the composite. When implanted in metal matrix a composite Al_2O_3 certainly improves the overall strength of the composite also it improves tensile strength and wear resistance. It also increases the hardness with increasing the reinforcement of the composite.

B. Magnesium [Mg]

The name magnesium originates from the Greek word for a district in Thessaly called Magnesia. Is the fourth most common element in the Earth as a whole (behind iron, oxygen and silicon), making up 13% of the planet's mass and a large fraction of the planet's mantle. The relative abundance of magnesium is related to the fact that it easily builds up in supernova stars from a sequential addition of three helium nuclei to carbon (which in turn is made from three helium nuclei). Due to magnesium ion's high solubility in water, it is the third most abundant element dissolved in seawater. The main applications of magnesium are, in order: component of aluminium alloys, in die-casting (alloyed with zinc), to remove sulfuring the production of iron and steel, the production of titanium in the Kroll process. Magnesium, in its purest form, can be compared with aluminium, and is strong and light, so it is used in several high volume part manufacturing applications, including automotive and truck components. Specialty, high-grade car wheels of magnesium alloy are called 'mag wheels', although the term is often more broadly misapplied to include aluminium wheels (Ball 1956).

C. Graphite [Gr]

The mineral graphite is an allotrope of carbon. It was named by Abraham Gottlob Werner in 1789 from the Ancient Greek its use in pencils, where it is commonly called lead (not to be confused with the metallic element lead). Unlike diamond (another carbon allotrope), graphite is an electrical conductor, a semimetal. It is, consequently, useful in such applications as arc lamp electrodes. Graphite is the most stable form of carbon under standard conditions. Therefore, it is used in thermo chemistry as the standard state for defining the heat of formation of carbon compounds. Graphite may be considered the highest grade of coal, just above anthracite and alternatively called meta-anthracite, although it is not normally used as fuel because it is difficult to ignite (Danilenko 2004).
In Al-Gr conman action percentage of elongation increases with reducing of hardness and tensile strength By increasing of graphite reinforcement the wear can reduce up to 5 to 7%. Due to less hardness Volumetric wear rate can increases (Singh, Narang et al. 2013).

D. Fly ash

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium (CaO), both being endemic ingredients in many coal-bearing rock strata (Adriano, Page et al. 1980). By increasing the fly ash reinforcement dry sliding wear can be reduce compare with un-reinforcement material. In this co-efficient friction can be increased but abrasive wear can be reduce (Surappa 2008).

V. MANUFACTURING AND FORMING METHODS

MMC manufacturing can be broken into three types: solid, liquid, and vapor (Clyne and Withers 1995).

A. Liquid State Methods

1) Electroplating / Electroforming: A solution containing metal ions loaded with reinforcing particles is co-deposited forming a composite material.
2) Stir casting: Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify.
3) Squeeze casting: Molten metal is injected into a form with fibers preplaced inside it.
4) Spray deposition: Molten metal is sprayed onto a continuous fiber substrate.
5) Reactive processing: A chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement.

B. Stir-casting or Compo Casting

According to the type of reinforcement, the fabrication techniques can vary considerably. From the contributions of several researchers, some of the techniques for the development of these composites are stir casting, powder metallurgy spray atomization and co-deposition, plasma spraying and squeeze-casting. The above processes are most important of which, liquid metallurgy technique has been explored much in these days. This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Ceramic particles and ingot-grade aluminum are mixed and melted. The melt is stirred slightly above the liquids temperature (600−700°C). Stir casting offers better matrix-particle bonding due to stirring action of particles into the melts. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles. Disadvantages that may occur if process parameters are not adequately controlled include the fact that non-homogeneous particle distribution results in sedimentation and segregation (Kwok and Lim 1999, Sharma 2001, Rosenberger, Schvezov et al. 2005).

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VI. EXPERIMENTATION

A. Composition In Weight Percentage

Composition in. Wt %				
Sample No	Mg	Al_2O_3	Fly ash	Al
1	3	-	-	100
2	3	5	-	92
3	3	10	-	87
4	3	-	5	92
5	3	-	10	87
6	3	5	5	87
7	3	5	10	82
8	3	10	5	82
9	3	10	10	77

Table: Composition in Weight Percentage

B. Composition Weight In Grams

Composition in gm				
Sample No	Mg	Al_2O_3	Fly ash	Al
1	-	-	-	300
2	4.9	15.13	-	242.76
3	4.9	30.25	-	229.56
4	4.9	-	10.84	242.76
5	4.9	-	21.67	229.56
6	4.9	15.13	10.84	229.56
7	4.9	15.13	21.67	216.36
8	4.9	30.25	10.84	216.36
9	4.9	30.25	21.67	203.18

Table: Composition Weight in grams

C. Stir Casting

The Stir casting method (also called liquid state method) is used for the hybrid composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies.

In this study, the aluminium-Al_2O_3, aluminum- fly ash, aluminium-Al_2O_3-fly ash and aluminium-fly ash-Al_2O_3 metal matrix hybrid composite was prepared by stir casting route. For this we have chosen desired amount of Al_2O_3, fly ash reinforcement mixtures in powder form. The fly ash and Al_2O_3 and their mixture were preheated to 300°C f or three hours to remove moisture. Aluminum alloy 7075 was melted in a resistance furnace. The melt temperature was raised up to 720°C and then the melt was stirred with the help of a mild steel turbine stirrer. The stirring was maintained between 5 to 7 min at an impeller speed of 200 rpm. To increase the wettability, 3% of pure Mg was added with all composites. The melt temperature was maintained 700°C during addition of Mg, Al_2O_3, fly ash, Al_2O_3-fly ash mixture particles. The dispersion of fly ash and other particles were achieved by the vortex method. The melt with reinforced particulates were poured into sand mold.

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Figure: Stir casting unit

Figure: A Sample Piece heating at 700^0C

Figure: No. of pieces

Figure: Sample for the wear testing

In this study, the aluminium - Al_2O_3, aluminum - fly ash, aluminium -Al_2O_3 - fly ash and aluminium - fly ash - Al_2O_3 composite was prepared by stir casting method (Figure. 5.1). For this we have chosen commercially aluminium alloy 7075 and desired amount of Al_2O_3 and fly ash mixtures in powder form. The fly ash and Al_2O_3 mixture were preheated to 300°C for three hours to remove moisture. Aluminium was melted in a resistance furnace. The melt temperature was raised up to 720°C and the reinforcement is added to the aluminium then the melt was stirred with the help of a mild steel turbine stirrer. The stirring was maintained between 5 to 7 min at an impeller speed of 200 rpm. To increase the wettability, 3% of pure Mg was added with all composites.

VII. RESULTS AND DISCUSSION

A. Density

It was observed that the experimental density values of the Al and composites decreased linearly.

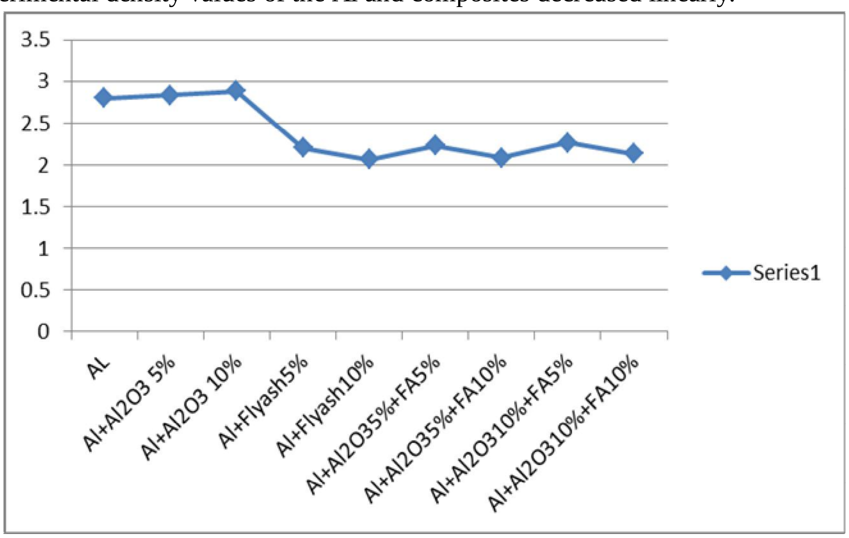

Figure: Variation of density with different compositions

The decrease in density of composites can be attributed to lower density of fly ash and Al_2O_3-fly ash particles than that of the unreinforced Al. It was also noted that the theoretical values closely matches with the experimental values. This indicates that the interface between matrix and reinforcement was almost perfectly bonded. Similar results were observed by Rao et al. (2010).

It is therefore, to improve the density again, apart from Al- Al_2O_3 and Al-fly ash composites, the mixture of Al_2O_3 and fly ash particles were added with aluminium. At higher concentration [(Al/(10%Al_2O_3+10%fly ash)], the density was decreased 2.12 g/cm^3. It is about 54% decreasing when compared aluminium alloy 7075.

B. Tensile Strength

The reinforcing phase in the metal matrix composites bears a significant fraction of stress, as it is generally much stiffer than the matrix. Micro plasticity in MMCs that takes place at fairly low stress has been attributed to stress concentrations in the matrix at the poles of the reinforcement and/or at sharp corners of the reinforcing particles (Corbin and Wilkinson, 1994). The increase in volume fraction of reinforcing particles initially decreases the micro yielding stress due to increase in number of stress concentration points . Mechanical behavior of Al-Al_2O_3 and Al-fly ash particles were already reported.

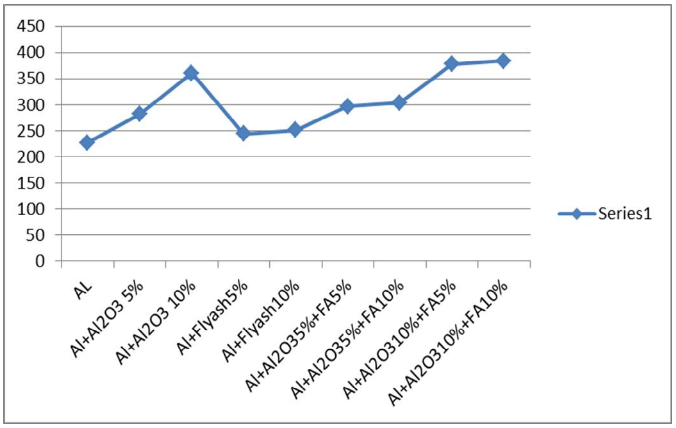

Figure: Variation of tensile strength with different compositions

The graph of the experimental tensile strength of the composites according to the Al_2O_3, fly ash and their mixtures is shown in Fig.6.2. Results show that the tensile strength of composites is higher than that obtained for the unreinforced Al. the tensile strength is increasing, which is about 57% improvement over that of the unreinforced Al matrix.

C. Hardness

The graph of the experimental hardness of the composites according to the Al_2O_3, fly ash and their mixtures is shown in Fig.6.3. As seen from the Fig. 10, an increasing trend of hardness was observed with increase in weight fraction of Al_2O_3, fly ash and their mixtures. It is observed that the maximum hardness is observed at Al(10%Al_2O_3+10%fly ash), which might leads to the deformation when subjected to strain. Incorporation of fly ash particles with this significantly improves the hardness and also the deformation of the Al matrix. It is observed that the fact that the combination of Al_2O_3 with fly ash particles possess higher hardness than the aluminium. Thus, it can be concluded that the mechanical properties such as density, tensile strength, yield strength and hardness of the composites increases by increasing Al_2O_3, fly ash and their mixtures. Contradictory, elongation of the hybrid metal matrix composite is very much decreased as that of the unreinforced aluminium. Addition of magnesium improves the wettability between the reinforcement particles and enhances the mechanical properties of the composites by solid solution strengthening. In addition, mechanical stirring in the semi-solid state enhances the uniform distribution between them.

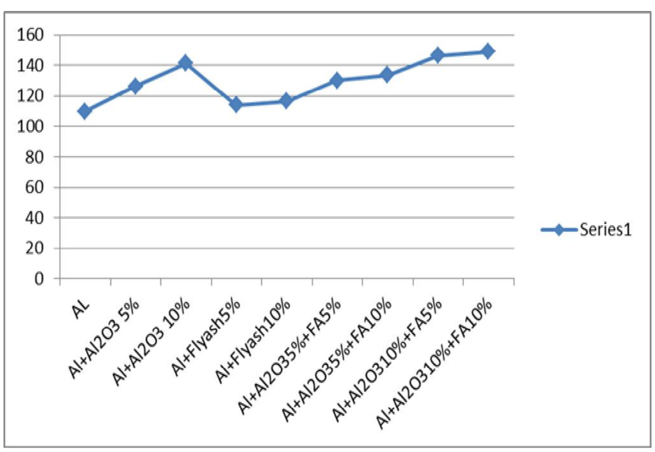

Figure: Variation of elongation with different compositions

D. Wear Rate

The wear rate is depending on the properties of the reinforcement and matrix material that we used. By changing the reinforcement percentage the properties can change. All the tests were conducted at atmospheric conditions. Below figure shows the variation of friction coefficient (μ) with sliding distance for both matrix alloy and composites at applied loads of 10 N, 20 N, , 40 N and 80 N with sliding speed of 1.45 m/s. The amplitude of the friction fluctuations was seen at all the stages. Due to sliding surface irregularities, the speed and applied load causes a typical stick-slip oscillation as observed in the frictional profiles. In all these cases the average coefficient of friction of the composite decreases with increasing reinforcement content.

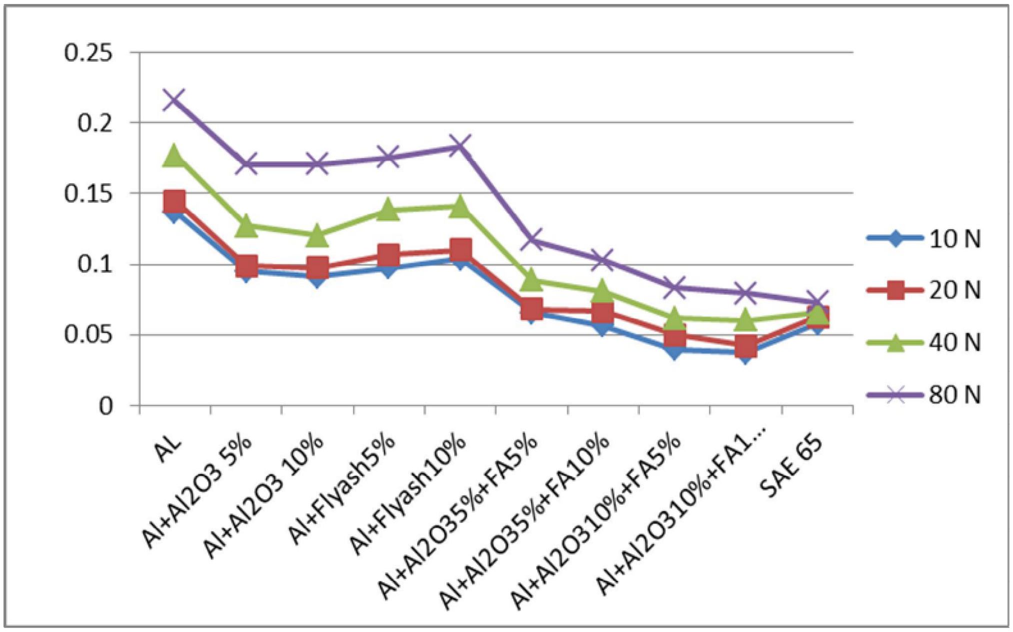

Figure: Variation of Volume loss with different compositions

It was observed that the coefficient of friction of matrix alloy and garnet reinforced composite material increases with increasing the load. It is observed from Fig. 6.4 that the stick-slip type frictional behavior of both unreinforced alloy and reinforced metal matrix composites decreases and is a function of sliding distance. The sliding surface is covered with alumina layer. This layer formed is very brittle and acts as an insulator. By superimposing the fig. 13 it can be observed that the wear rate of the composites samples increases as the load increases from 40N to 80N and also the trend in wear resistance can be found to be increasing with increase of ash content in the composites. This increase in wear resistance of the composite is due to the reason of the reinforcement material which is much harder than the matrix material Al. This increase in wear resistance can also be attributed to a better interfacial bonding b/w matrix and reinforcement particles thus helps in preventing the damages caused due to the sliding action.

VIII. CONCLUSION

Al-Al_2O_3, Al-fly ash, Al-Al_2O_3-fly ash (various concentrations) composites were successfully fabricated by two-step stir casting process. Wetting of reinforcements with the aluminium matrix was further improved by the addition of magnesium.

Based on the experimental observations the following conclusions have been drawn:

Density of the composites decreased by increasing the content of the reinforcement Hence, it was found that, instead of Al-fly ash composites, Al-Al_2O_3-fly ash composites show better performance. So these composites can be used in applications where to a great extent weight reductions are desirable. Tensile strength and hardness were determined for the test materials. Increase in area fraction of reinforcement in matrix result in improved tensile strength and hardness. With the addition of Al_2O_3 and fly ash with higher percentage the rate of elongation of the hybrid MMCs is decreased significantly. the wear rate various according to the properties of the reinforcement and matrix material, wear can reduce by increasing the strength of composite. From the above results we can conclude that instead of Al-Al_2O_3 or Al-fly ash composites, the Al-Al_2O_3-fly ash composites could be considered as an exceptional material in sectors where lightweight and enhanced mechanical properties are essential.

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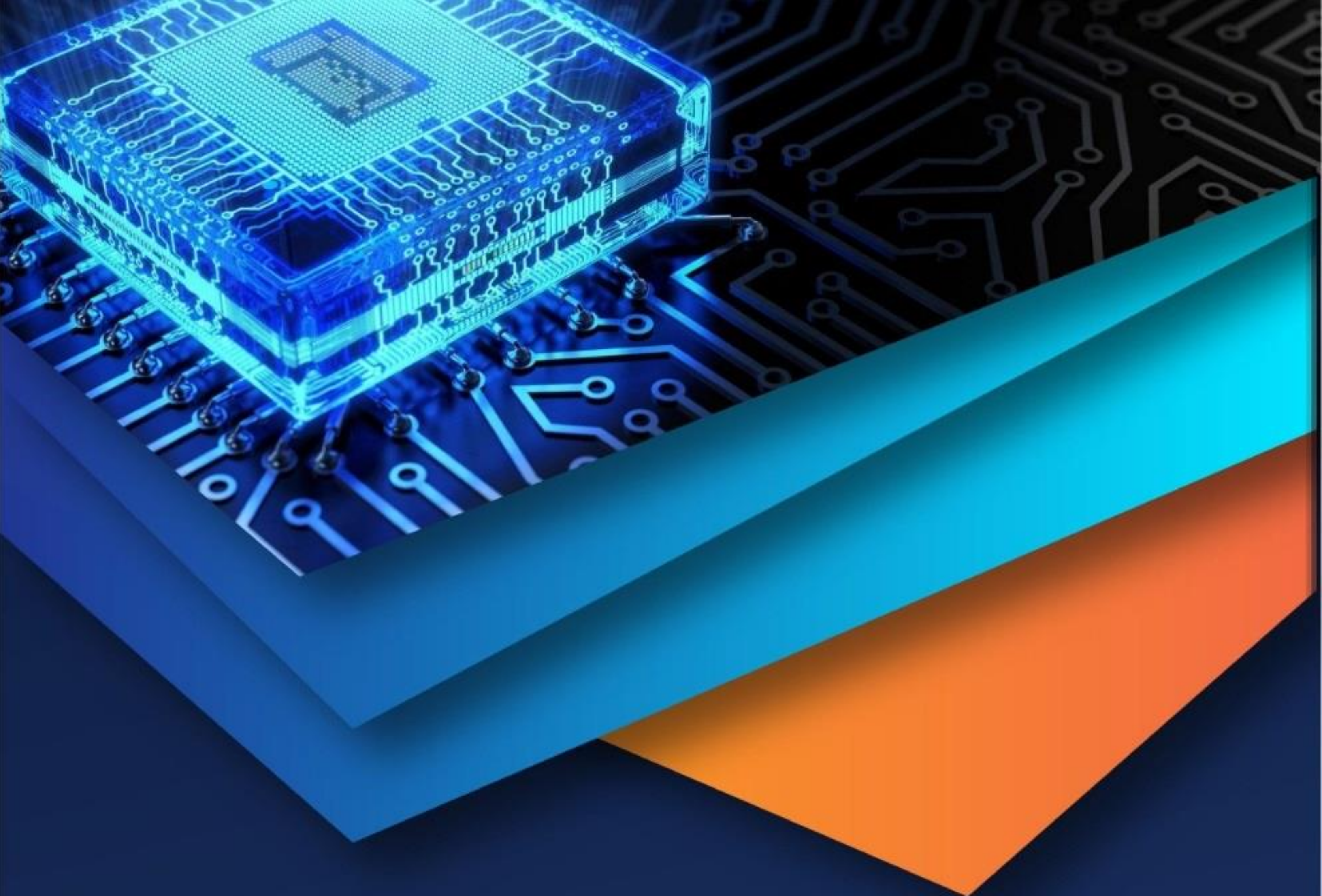

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